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RESEARCH MEMORANDUM

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BELL X-1 AIRPLANE MEASURED IN
TRANSONIC FLIGHT

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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AILERON AND ELEVATOR HINGE MOMENTS OF THE
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SUMMARY

The National Advisory Committee for Aeronautics is conducting a transonic flight research program utilizing the Bell X-1 airplane having the 10-percent-thick wing and 8-percent-thick horizontal tail. As part of this program the hinge moments were measured on the 20-percent-chord unbalanced elevator and the 15-percent-chord unbalanced aileron. The range of Reynolds number was from 3.0×10^6 to 5.5×10^6 for the elevator data and from 6.0×10^6 to 9.0×10^6 for the aileron data.

It was found that the variation of hinge-moment coefficient with aileron deflection $C_{h\delta_a}$ had a value of -0.010 up to a Mach number of 0.85 and then increased gradually to a value of -0.025 at a Mach number of 0.97. This value was maintained to a Mach number of 1.13, the limit of the tests. The variation of hinge-moment coefficient with elevator deflection $C_{h\delta_e}$ had the same value as the subsonic value for the aileron to a Mach number of 0.96 where it started to increase abruptly, reaching a value of -0.022 at a Mach number of 0.99. The value of $C_{h\delta_e}$ was then constant to a Mach number of 1.18, the limit of these tests. The variation of hinge-moment coefficient with angle of attack for the aileron $C_{h\alpha_a}$ was found to have a value of about -0.002 to a Mach number of 0.80 where it started to increase reaching a value of -0.017 at a Mach number of 0.92 and retaining this value to a Mach number of 1.09, the limit of these tests.

The variations with Mach number of hinge-moment coefficients for the aileron due to both control deflection and angle of attack obtained by pressure-distribution measurements are in good agreement with the results of the strain-gage measurements. The values measured in flight are in good agreement with low-speed tunnel tests.

INTRODUCTION

The NACA is conducting research on the transonic flight characteristics of the Bell X-1 research airplane as a part of the joint Air Force—Navy—NACA high-speed flight research program. During the flight investigation of the X-1 airplane the hinge moments of the elevator and aileron control surfaces have been measured over a Mach number range extending to above 1.0. The results of these measurements are presented in this paper.

SYMBOLS

b	local control span, in.
C_h	hinge-moment coefficient, $H/qb\bar{c}^2$
$C_{h\alpha}$	variation of hinge-moment coefficient with angle of attack per degree, $dC_h/d\alpha$
$C_{h\delta}$	variation of hinge-moment coefficient with deflection per degree, $dC_h/d\delta$
C_{N_A}	airplane normal-force coefficient, nW/qS
c	local chord of control surface, ft
$\bar{c}$	average chord of control surface, ft
c_n	section normal-force coefficient, $\int_0^1 P_R d\frac{x}{c}$
F_e	elevator wheel force, lb
g	acceleration due to gravity, ft/sec ²
H	hinge moment of control surface, in.-lb
M	free-stream Mach number
n	normal acceleration, g units

P	pressure coefficient, $\frac{p_l - p_u}{q}$
p_l	static pressure on lower surface, lb/sq ft
p_u	static pressure on upper surface, lb/sq ft
q	dynamic pressure, lb/sq ft
S	wing area, sq ft
t	time, sec
W	airplane weight, lb
x	chordwise distance from leading edge of local chord, ft
α	angle of attack, deg
δ	control angle, deg
$\dot{\theta}$	pitching velocity, radians per sec
$\dot{\phi}$	rolling velocity, radians per sec

Subscripts:

a	aileron
e	elevator
L	left
W	wing
t	tail

AIRPLANE AND INSTRUMENTATION

The X-1 airplane is a rocket-propelled single-place straight-wing monoplane designed for conducting flight research in the transonic speed range. A sketch of the airplane is shown as figure 1 and sketches of the aileron and elevator control surfaces are shown as figures 2 and 3. The wing incorporates an NACA 65-110 airfoil section with the cusp replaced by a flat-sided taper from 0.85 chord to the trailing edge. The horizontal tail is an NACA 65-008 airfoil section.

The aileron hinge moments were measured by means of strain gages placed in the control linkage and pressure orifices distributed as shown in figure 2. The elevator hinge moments were obtained from the elevator wheel force measurements. The elevator friction was ± 4 pounds. Standard NACA recording instruments recorded altitude, airspeed, angle of attack, rolling velocity, three components of acceleration, aileron hinge moment, elevator wheel force, aileron angle, elevator angle, stabilizer angle, and pitching velocity. All records were synchronized by a common timer.

The elevator angle was measured with respect to the stabilizer at the airplane center line and the aileron angle was measured on the aileron linkage close to the aileron.

PROCEDURE

Test Conditions

Pull-ups, aileron rolls, and level flight runs were made to obtain aileron and elevator hinge moments at altitudes between 35,000 and 45,000 feet except for those data obtained at Mach numbers below 0.7 which were obtained from flights at an altitude of 25,000 feet. The Mach number range covered was from 0.52 to 1.18 for $C_{h\delta_e}$, from 0.50 to 1.13 for $C_{h\delta_a}$, and from 0.7 to 1.09 for $C_{h\alpha_a}$. The Reynolds numbers

of the aileron tests varied from 6×10^6 to 9×10^6 , based on the chord of the wing at the aileron mean chord station, whereas the Reynolds numbers for the elevator tests were between 3×10^6 and 5.5×10^6 , based on the mean aerodynamic chord of the horizontal tail.

Strain-Gage and Wheel-Force Measurements

The elevator hinge-moment coefficient $C_{h\delta_e}$ was determined during pull-ups using the elevator by measuring the variation of elevator force with elevator deflection during that portion of the pull-up when the control had moved but the airplane had not as yet changed angle of attack more than 1° . At low Mach numbers the response of the airplane was very rapid and it was necessary to use data obtained when the change in angle of attack was as much as 2° . A change of angle of attack of this magnitude would produce an error of about 10 percent in the value of $C_{h\delta}$. Examples of these maneuvers are presented in figure 4.

It has not proved feasible to measure $C_{h\alpha_e}$ because the friction in the elevator system was sufficiently large to mask $C_{h\alpha_e}$ in trim runs and the stabilizer can be moved only through small deflections in maneuvers without causing considerable acceleration of the airplane.

The variation of $C_{h\delta_a}$ was measured in abrupt aileron rolls by measuring the variation of hinge moment with aileron angle before a rolling velocity greater than 0.01 radian per second was developed. This rate of roll would produce a change in angle of attack less than 0.1° at the aileron. Because of these restrictions some of the values of hinge-moment parameters were obtained only for comparatively small ranges of control angles. Maneuvers of this type are shown in figure 5.

The variation of $C_{h\alpha_a}$ was measured during symmetrical pull-ups performed with the ailerons fixed. Some maneuvers performed for this purpose are shown in figure 6.

Pressure-Distribution Measurements

Flights were made with both ailerons rigged up or down enabling $C_{h\delta_a}$ to be obtained in nonrolling flight. This was necessary because of the lag resulting from the pressure tubing. The value of $C_{h\alpha_a}$ was determined by measurements made during pull-ups with the ailerons held fixed.

RESULTS AND DISCUSSION

Hinge Moments Caused by Control Deflection

Aileron control surface.— The variation of $C_{h\delta_a}$ with Mach number as measured by both strain gages and pressure distributions is shown in figure 7. These data show that the low-speed value of -0.010 is maintained essentially constant to a Mach number of about 0.85 where it starts to increase negatively, reaching a value of about -0.025 at $M = 0.97$. This value is then maintained to $M = 1.13$, the limit of these tests. The results of the strain-gage and pressure-distribution measurements are in satisfactory agreement throughout the Mach number range.

The hinge-moment coefficients measured in flight are compared in figure 7 with the results of the low-speed tests reported in reference 1. The low-speed data are extrapolated by means of the Prandtl-Glauert correction and show good agreement with the flight measurements.

The reasons for the changes in $C_{h\delta_a}$ with Mach number may be seen from the pressure distributions presented in figure 8. The effects of increasing upward control angle are generally the same at $M = 0.53$ and $M = 0.75$ (figs. 8(a) and 8(b)) consisting of a reduction in upper-surface suction as the control is moved through zero to up deflections. However, at $M = 0.89$ and 0.93 (figs. 8(c) and 8(d)), the upper-surface suction first increases slightly as the control is moved above neutral and then decreases as the control is moved further. The suction on the lower surface increases considerably as the control is moved through zero but remains constant or decreases slightly at higher deflections. This results in a slight negative increase in the slope $C_{h\delta_a}$ to a value of about -0.015 from the low-speed value of -0.10 . With a further increase of Mach number to 0.99 (fig. 8(e)) the upper-surface suction is almost completely unaffected by upward control movement in the range tested while the lower surface has a considerable suction pressure which is increased as the control is deflected up. This increase in lower-surface suction produces an increase in hinge moment to a value of -0.025 .

Elevator control surface.— The variations of the measured values of $C_{h\delta_e}$ with Mach number are presented in figure 9. These data indicate a variation with Mach number similar to that measured for the aileron control. There is a slight decrease in the negative value of $C_{h\delta_e}$ at $M = 0.94$ and the change to the supersonic value of $C_{h\delta_e} = -0.022$ occurs at a Mach number of 0.99 rather than near 0.93 as was the case for $C_{h\delta_a}$ shown in figure 7. The low-speed tunnel data reported in reference 2 and extrapolated to the flight Mach numbers are in reasonable agreement with the flight results.

Hinge Moments Caused by Angle of Attack

Aileron control surface.— The measured variation of $C_{h\alpha_a}$ with Mach number is presented in figure 10. The subsonic value is quite low, about -0.002 , but at a Mach number of about 0.8 , $C_{h\alpha_a}$ starts to increase negatively. This low-speed value is in agreement with the

extrapolated tunnel data of reference 1. The data are not sufficient to define the increase in $C_{h\alpha_a}$ as well as the increase in $C_{h\delta_a}$ was defined, but it appears to take place rather abruptly at about $M = 0.88$. The supersonic value of -0.017 is maintained to $M = 1.09$, the limit of these tests.

Figure 11 presents the aileron loadings at various angles of attack over the Mach number range. The variation of aileron loading as the angle of attack is increased at $M = 0.73$, shown in figure 11(a), is so very slight that it is difficult to determine the hinge-moment coefficients by the use of pressure-distribution measurements. At the higher Mach numbers the changes with angle of attack are considerably larger. These results (figs. 11(b) to 11(d)) indicate that the increase in hinge moment arises from a general increase in upper-surface suction with increasing angle of attack for the two inboard stations. The loading of the outboard station does not appear to be affected by angle of attack for angles of attack less than about 8° . Because the curves of hinge moment plotted against α obtained from the load distributions are very nonlinear, the value of $C_{h\alpha}$ thus obtained is not very accurate. The values shown in figures 10 and 11 are believed, however, to be reasonable based on the data of figure 11 and are in agreement with the strain-gage result in figure 10.

CONCLUSIONS

From aileron and elevator hinge-moment measurements in flight of the Bell X-1 airplane having the 10-percent-thick wing and 8-percent-thick tail, the following conclusions have been drawn:

1. The variation of hinge-moment coefficient with aileron deflection $C_{h\delta_a}$ was constant at -0.010 to a Mach number of 0.85 . Between Mach numbers of 0.85 and 0.97 the value of $C_{h\delta_a}$ gradually increased in the negative direction to -0.025 which value was retained to a Mach number of 1.13 , the limit of these data.

2. The variation of hinge-moment coefficient with elevator deflection $C_{h\delta_e}$ was similar to the variation of hinge-moment coefficient with aileron deflection $C_{h\delta_a}$ except that the increase from the subsonic value of -0.010 was more abrupt, starting at a Mach number of 0.96 and reaching a value of -0.022 at a Mach number of 0.99 . The value of

$C_{h\delta_e}$ remained constant between Mach numbers of 0.99 and 1.18, the limit of these data.

3. The variation of aileron hinge-moment coefficient with angle of attack $C_{h\alpha_a}$ had a value of about -0.002 between Mach numbers of 0.5 and 0.80 at which Mach number $C_{h\alpha_a}$ started to increase, reaching a value of -0.017 at a Mach number of 0.92 and retaining this value to a Mach number of 1.09, the limit of these data.

4. The variations with Mach number of hinge-moment coefficient caused by both control deflection and angle of attack for the aileron obtained from strain-gage measurements were in good agreement with data obtained from pressure-distribution measurements. The values of hinge-moment coefficient obtained were in good agreement with low-speed tunnel tests.

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REFERENCES

1. Kemp, W. B., and Polhamus, E. C.: Wind-Tunnel Tests of a 1/4-Scale Model of the Bell XS-1 Transonic Airplane (Army Project MX-653). II - Lateral and Directional Stability and Control. NACA MR L6E27, Army Air Forces and Bur. Aero., 1946.
2. Donlan, C. J., Kemp, W. B., and Polhamus, E. C.: Wind-Tunnel Tests of a 1/4-Scale Model of the Bell XS-1 Transonic Airplane (Army Project MX-653). I - Longitudinal Stability and Control Characteristics. NACA MR L6D12, Army Air Forces, 1946.

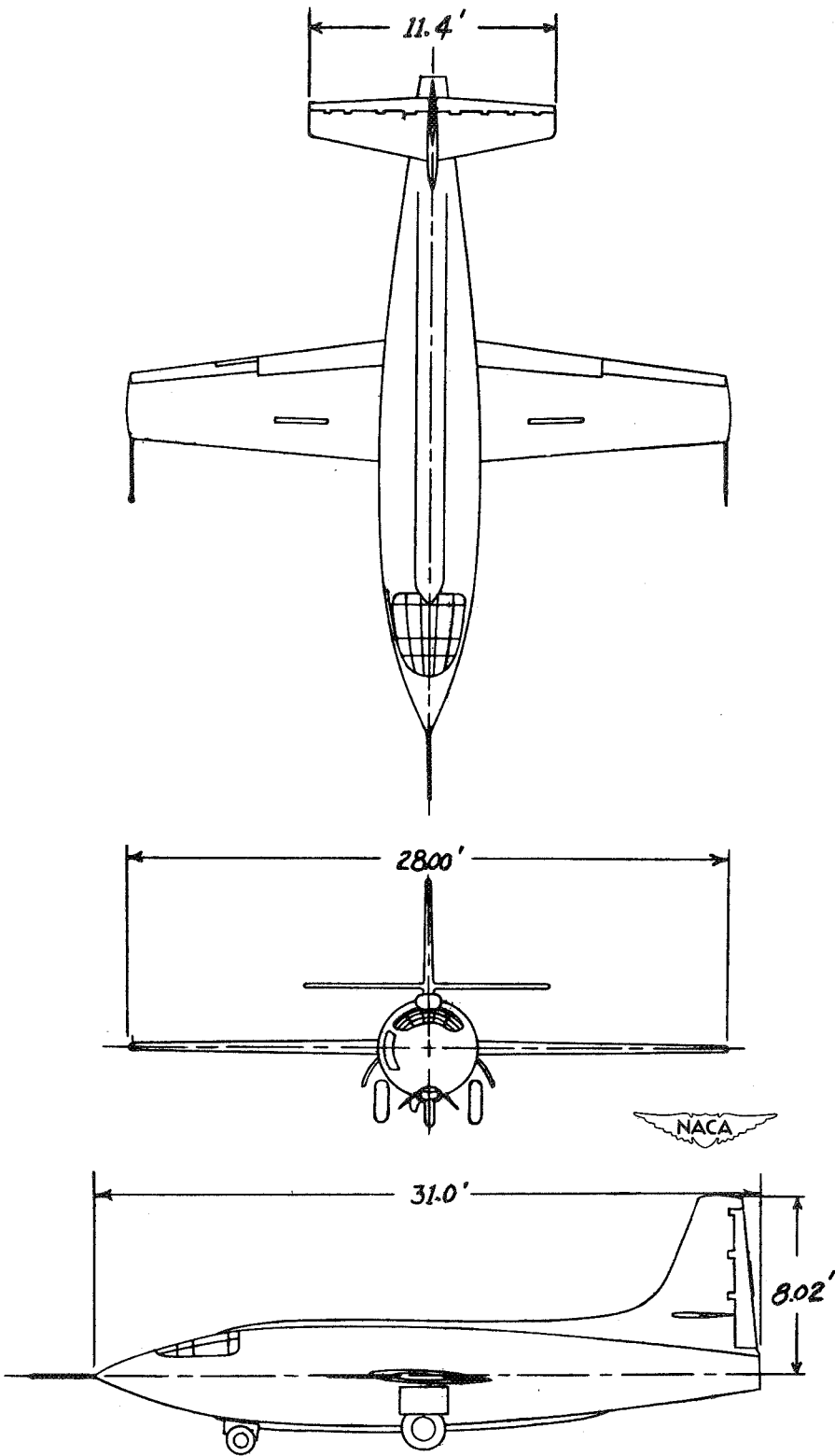
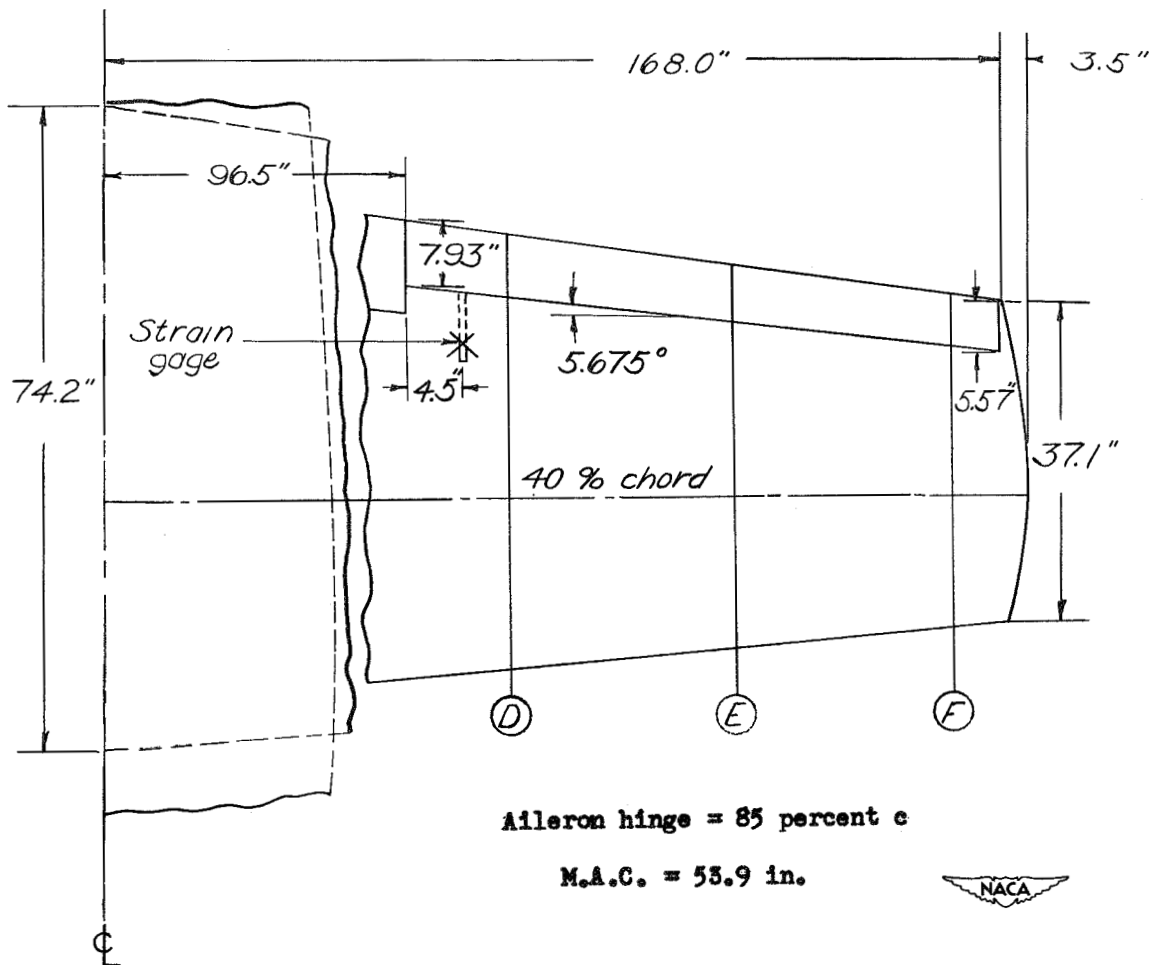


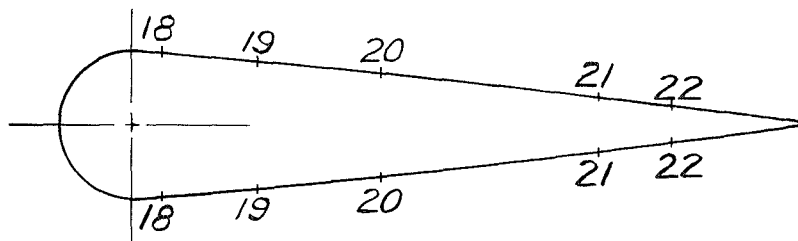
Figure 1.- Three-view drawing of Bell X-1 airplane.



Span station	D	E	F
Distance from airplane center line, percent b/2	64.4	79.8	95.1
Wing chord, in.	50.29	44.60	38.92
Distance from aileron root, in.	11.75	37.50	63.25
Aileron chord, in.	7.54	6.69	5.84

(a) Spanwise.

Figure 2.- Spanwise and chordwise locations of pressure measuring orifices on aileron of Bell X-1 airplane.



Orifice station location, percent chord						
Span station	D		E		F	
Orifice	Upper	Lower	Upper	Lower	Upper	Lower
18	85.62	85.40	85.70	85.70	85.70	85.70
19	87.35	87.35	87.50	87.55	87.65	87.60
20	90.00	90.00	89.95	89.95	89.60	89.60
21	95.00	95.00	95.00	95.30	95.10	95.30
22	97.10	97.00	96.70	96.45	96.10	96.10

(b) Chordwise.

Figure 2.- Concluded.

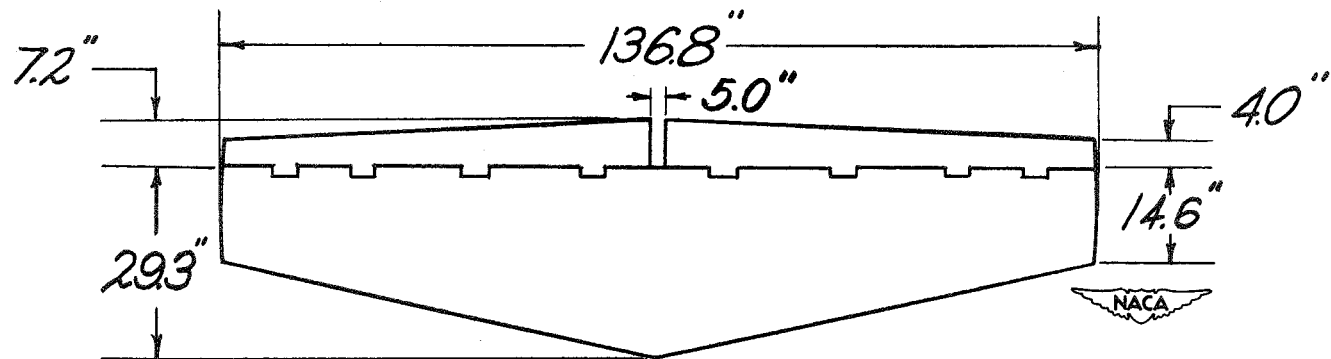


Figure 3.- Sketch of horizontal tail of Bell X-1 airplane. Airfoil section, root and tip: NACA 65-008.

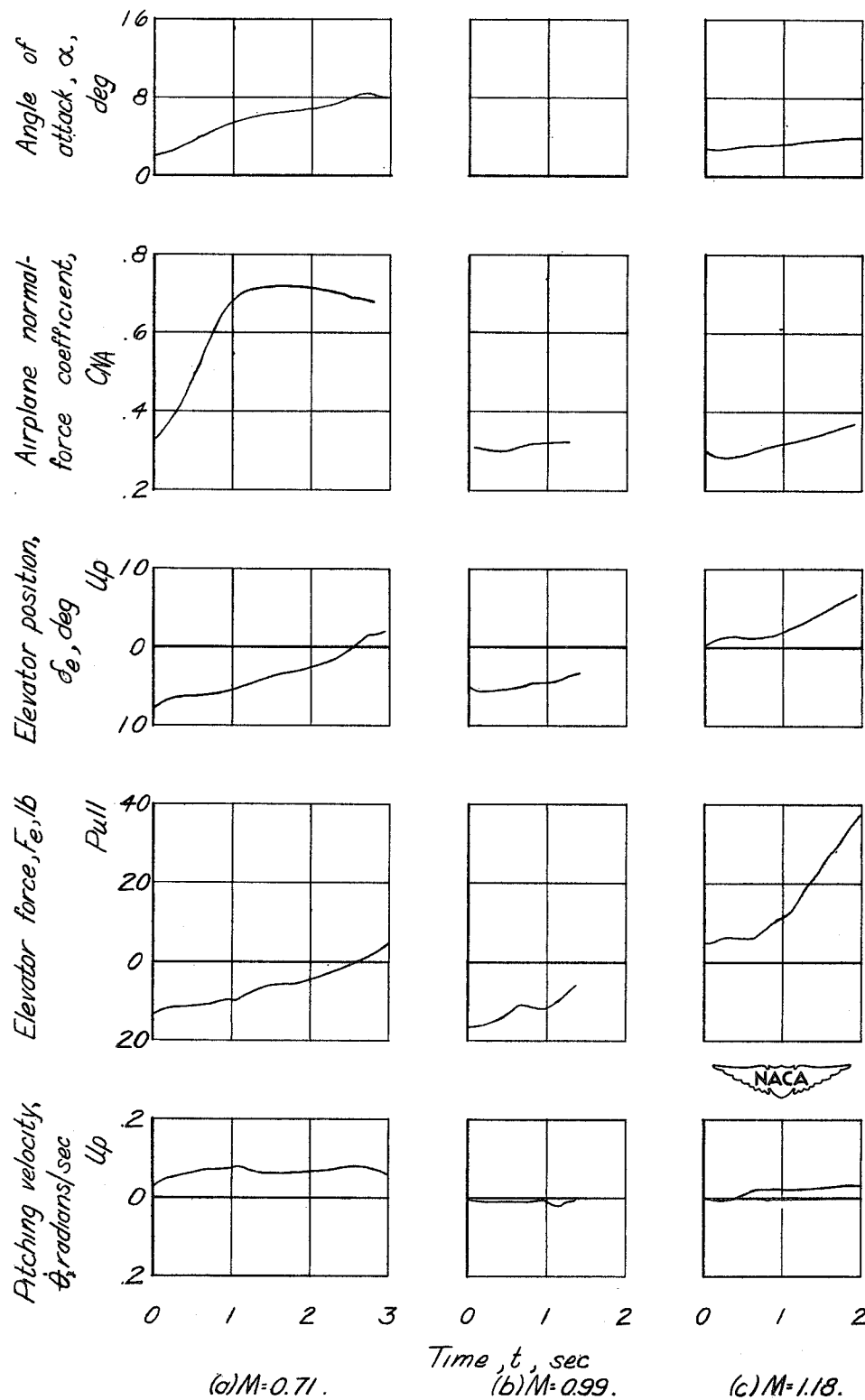


Figure 4.- Time histories of pull-ups used to determine hinge-moment coefficients due to elevator deflection.

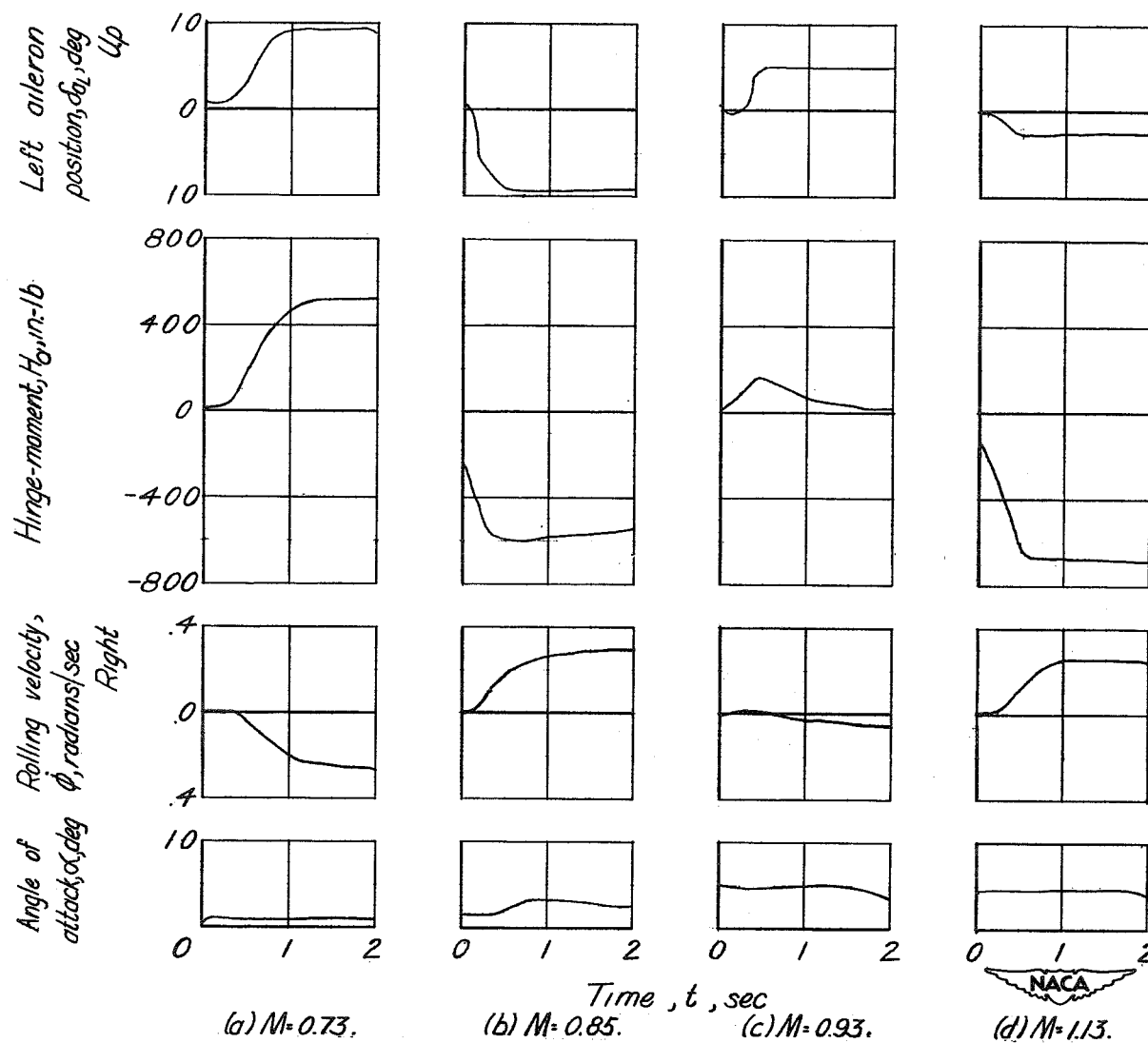


Figure 5.- Time histories of aileron rolls used to determine hinge-moment coefficients due to aileron deflection.

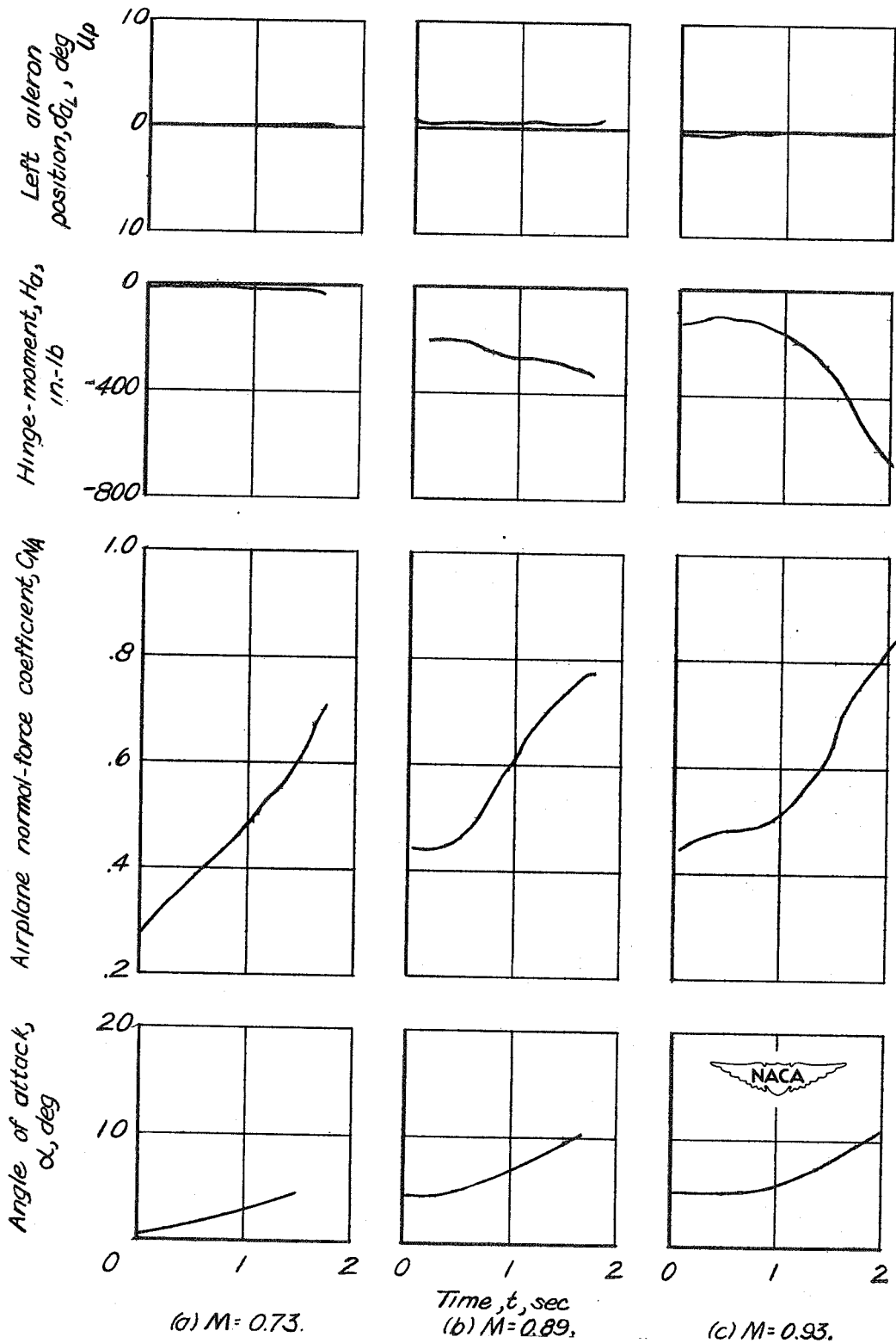


Figure 6.- Time histories of pull-ups used to determine aileron hinge-moment coefficients caused by angle of attack.

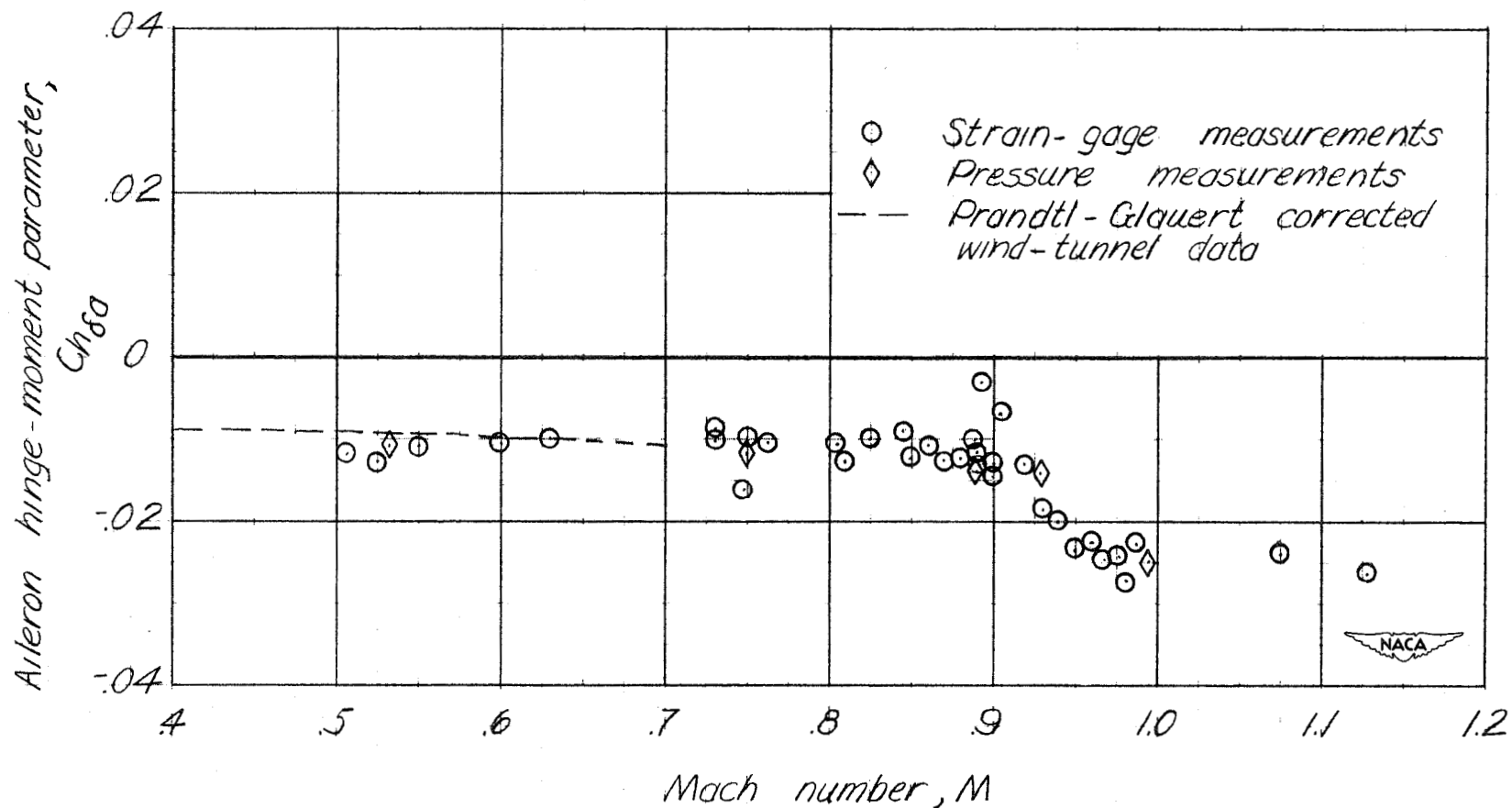


Figure 7.- Variation of $C_{h\delta_a}$ with Mach number for aileron of Bell X-1 airplane. Airfoil section, NACA 65-110; $c_a/c_w = 0.15$; trailing-edge angle, 11.2° .

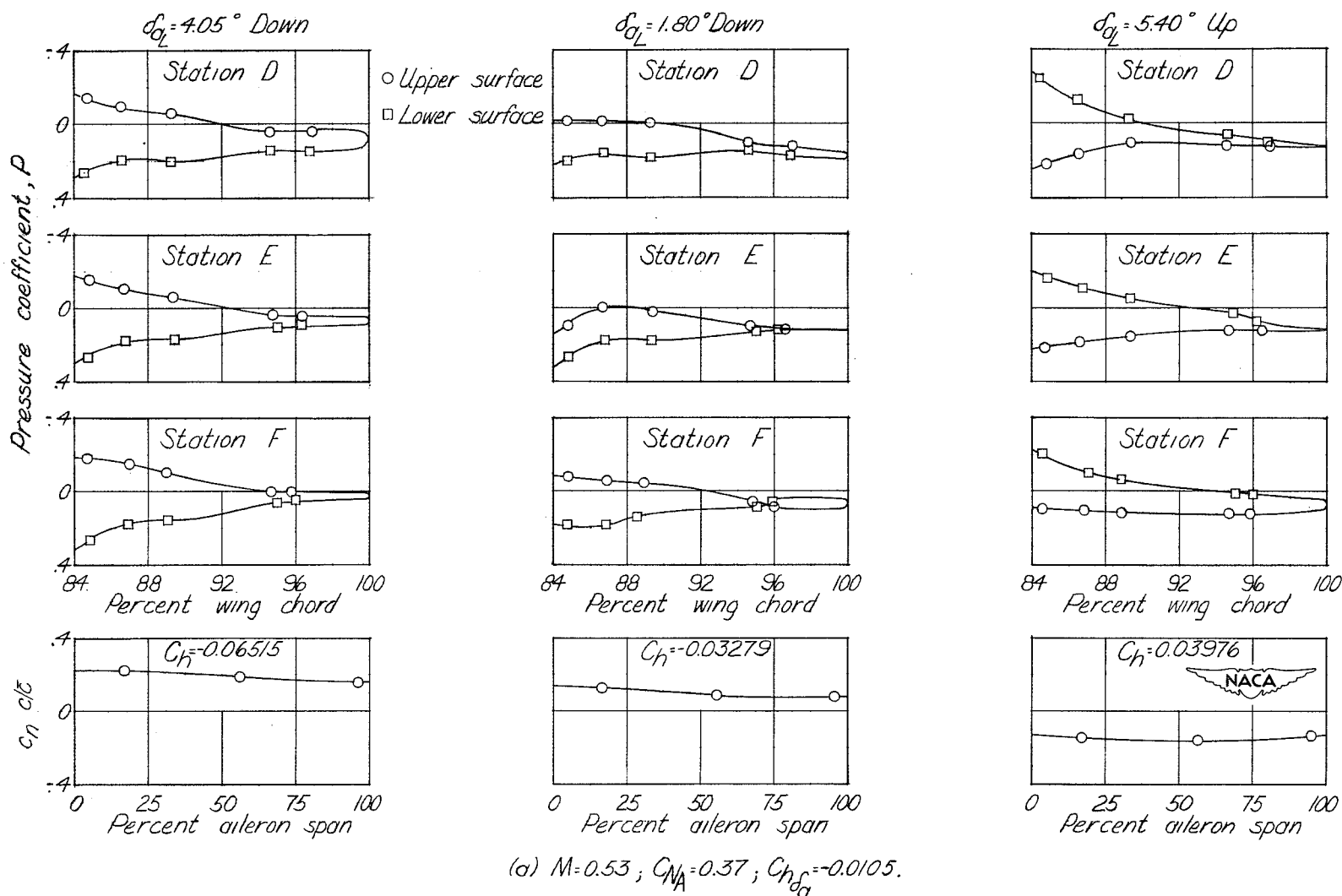


Figure 8.- Chordwise and spanwise load distributions over aileron at various aileron angles for constant Mach number and lift coefficient.

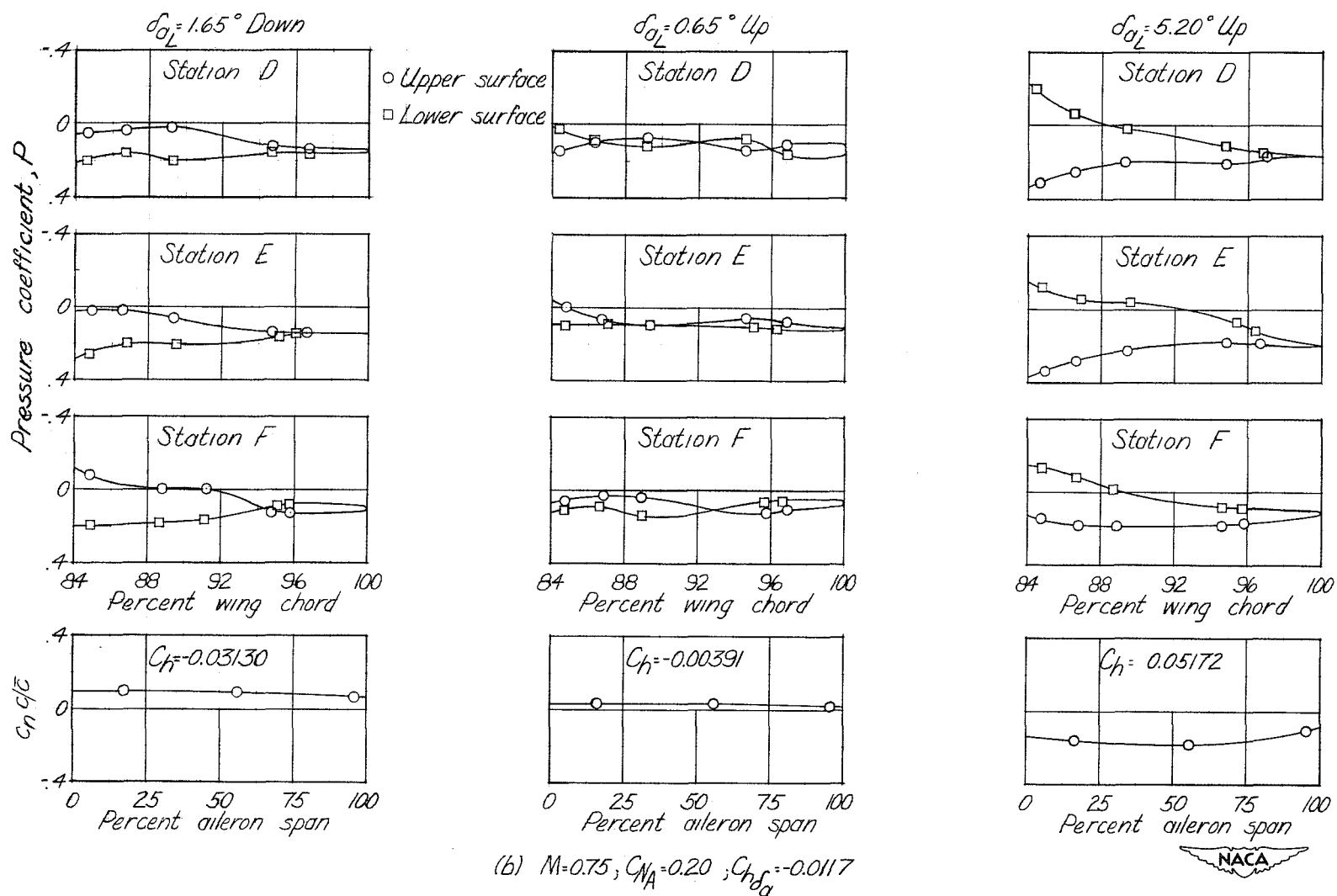


Figure 8.- Continued.

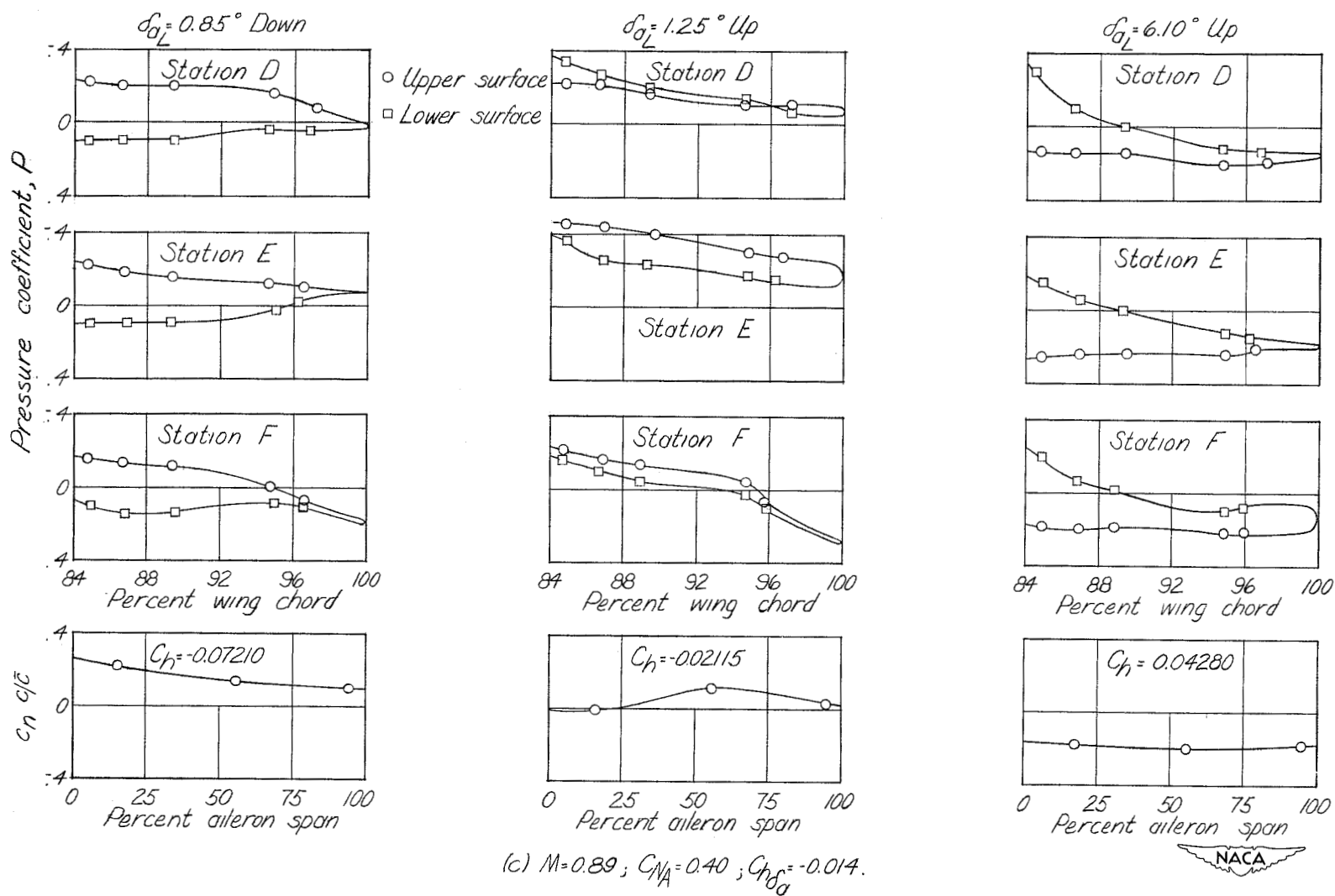


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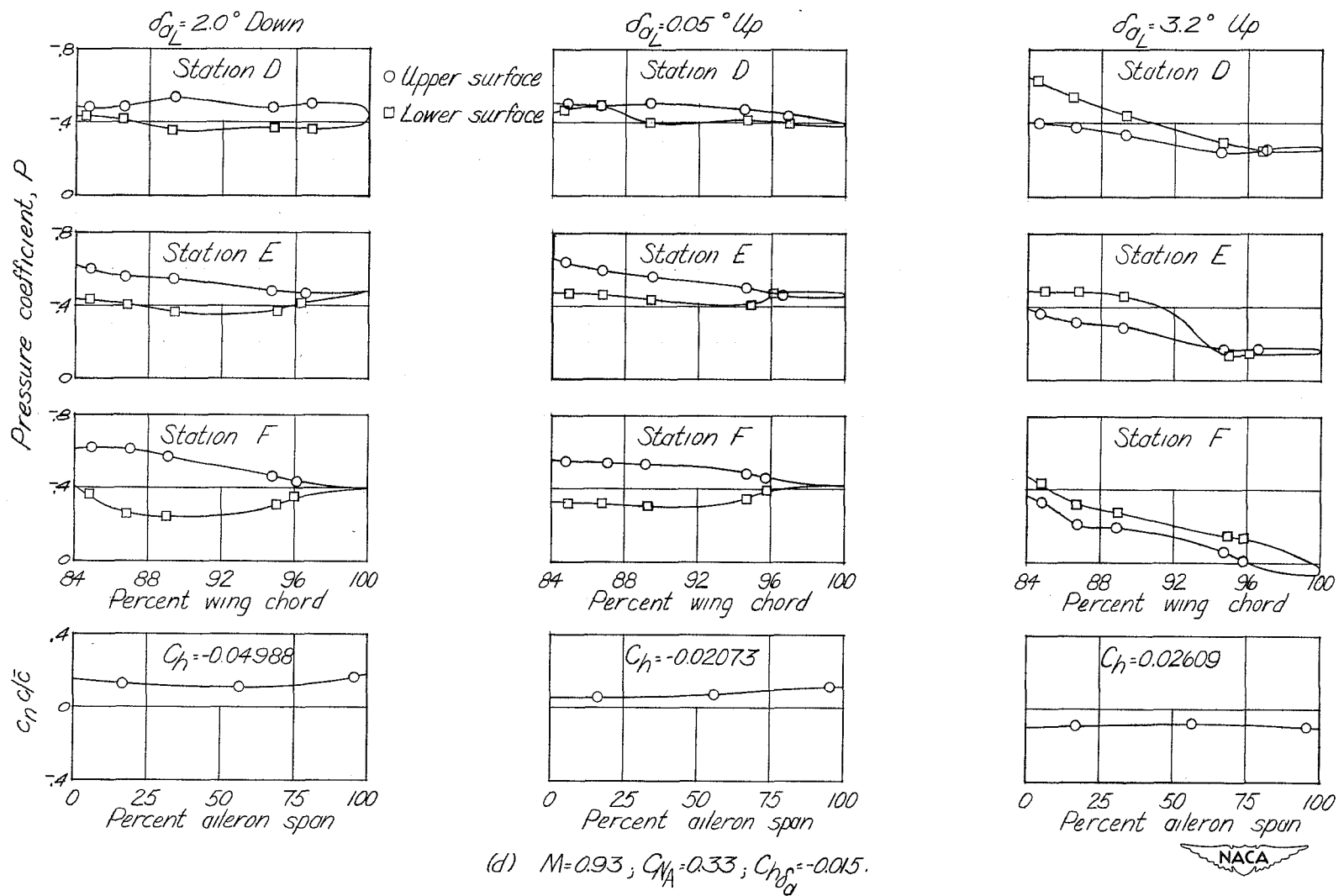


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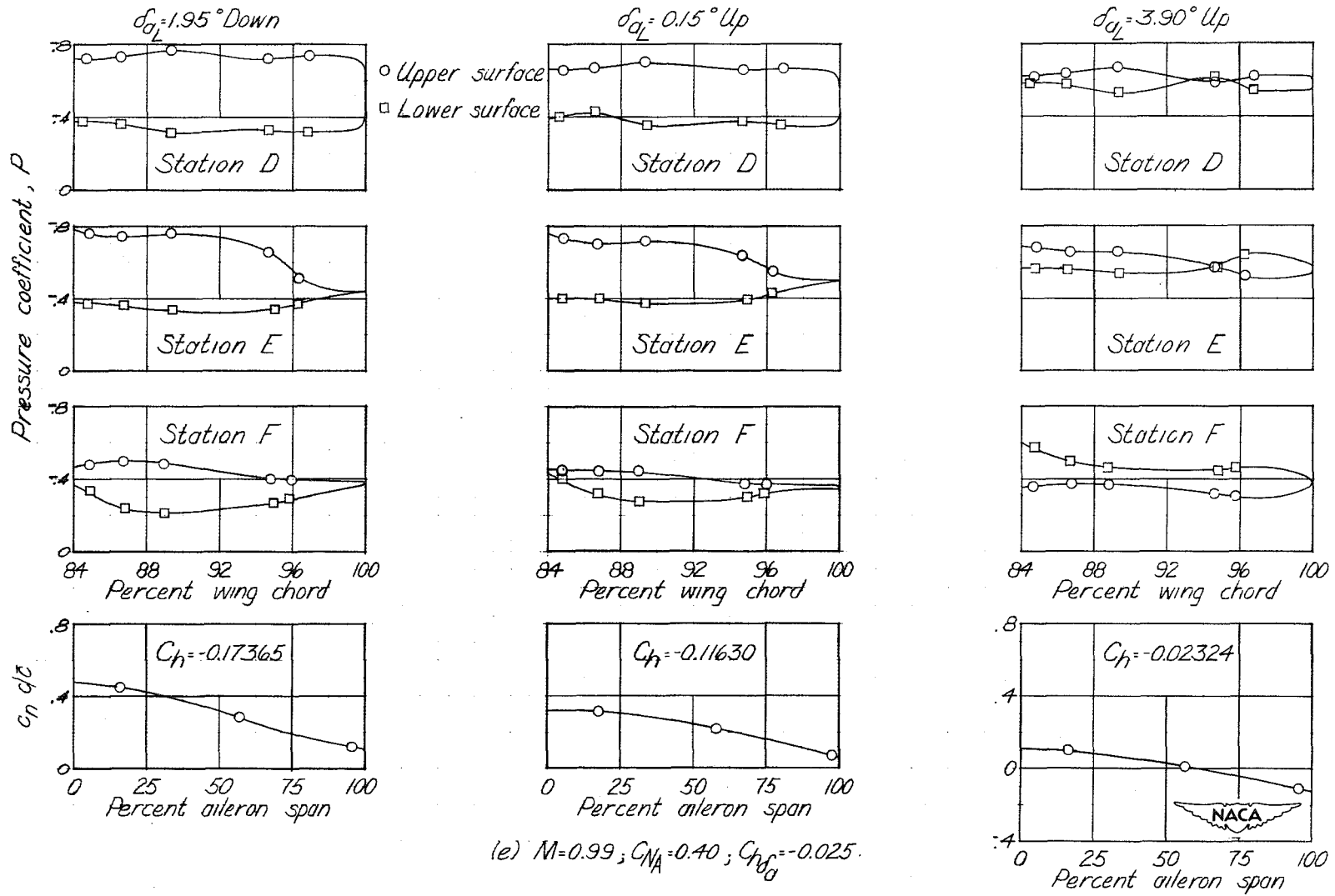


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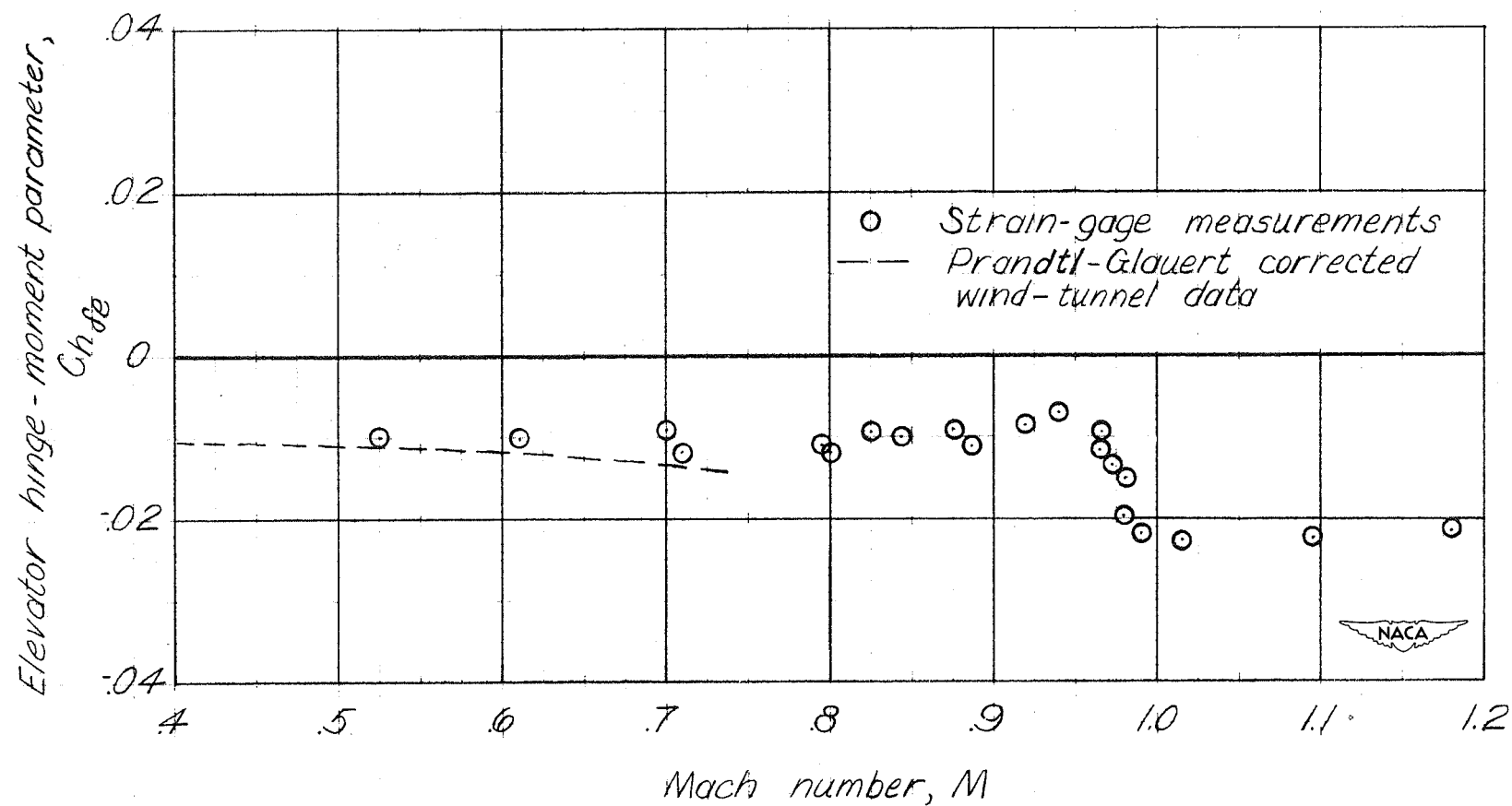


Figure 9.- Variation of $C_{h\delta_e}$ with Mach number for elevator of Bell X-1 airplane. Airfoil section, NACA 65-008; $c_e/c_t = 0.20$; trailing-edge angle, 9° .

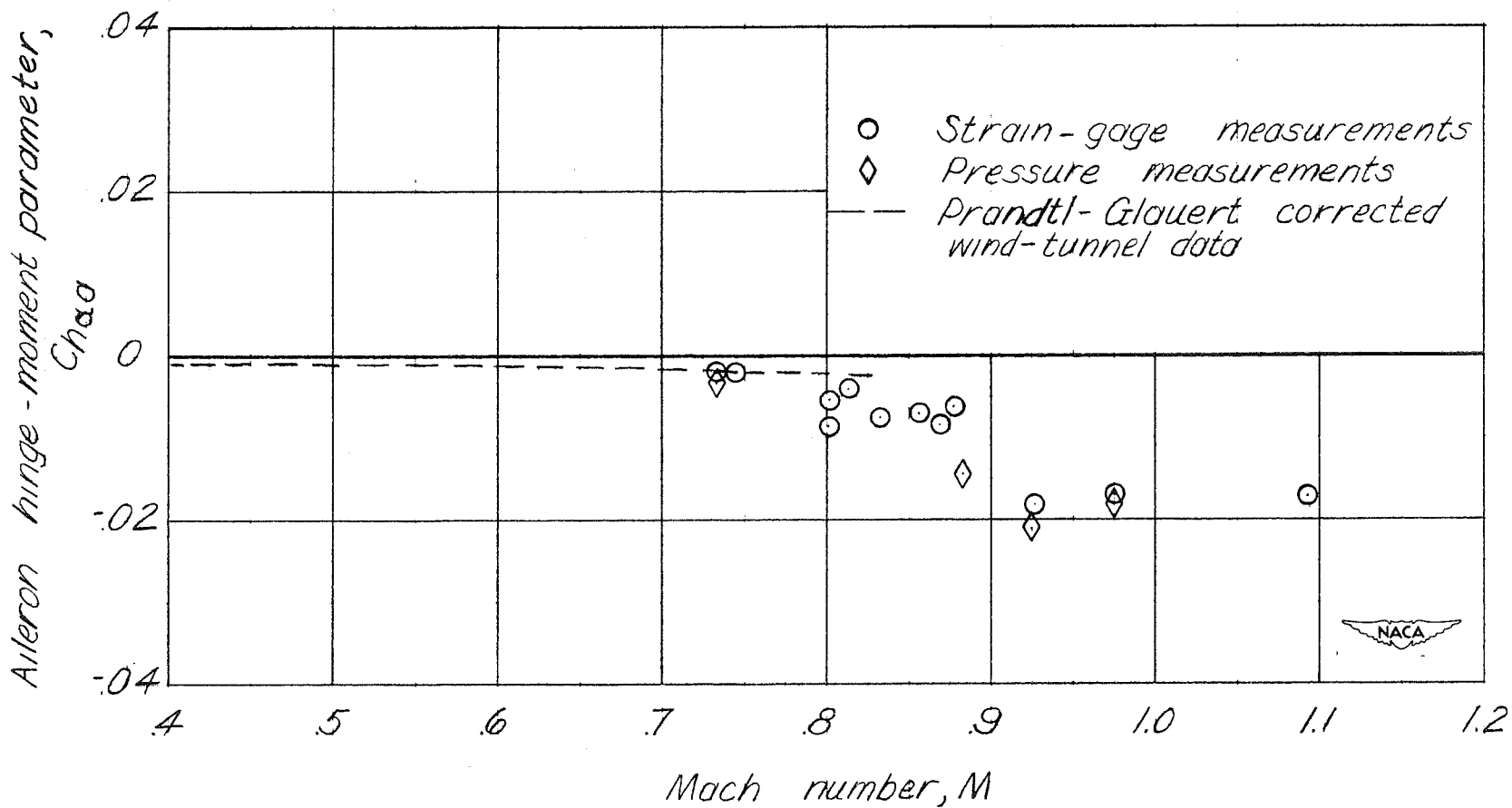


Figure 10.- Variation of $Ch_{\alpha a}$ with Mach number for aileron of Bell X-1 airplane. Airfoil section, NACA 65-110; $c_a/c_w = 0.15$; trailing-edge angle, 11.2° .

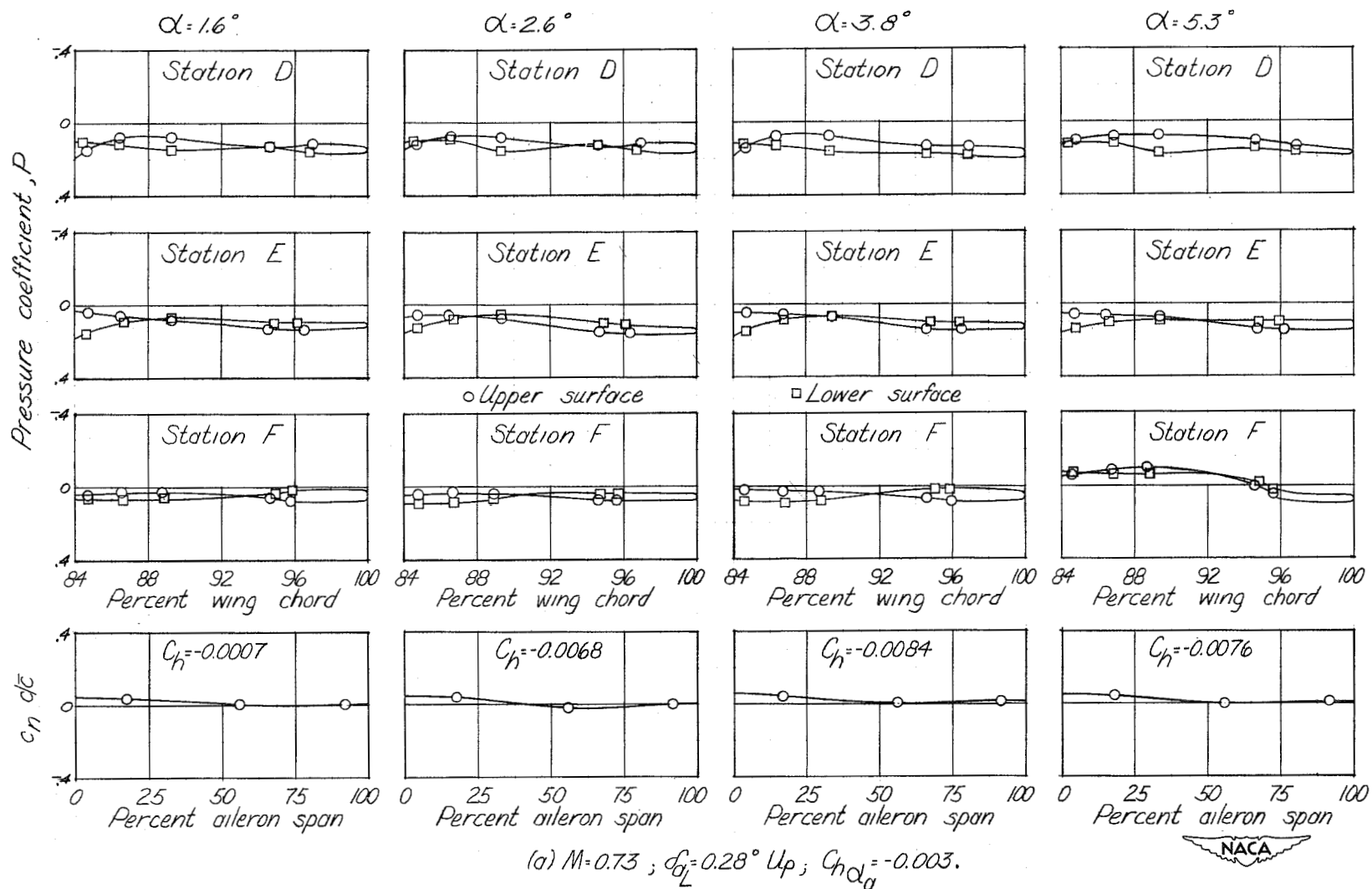
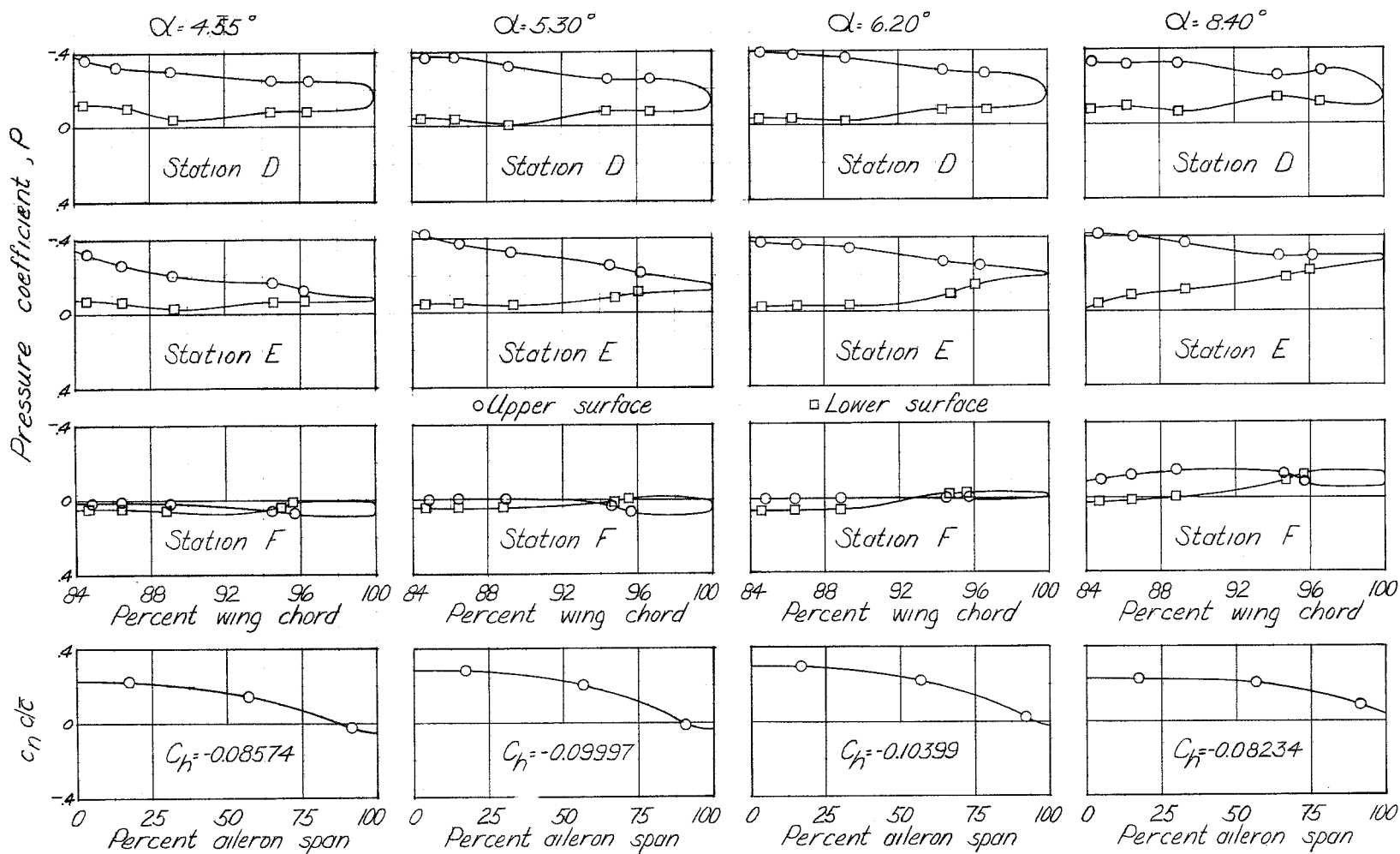


Figure 11.- Chordwise and spanwise load distribution over aileron for various angles of attack for constant Mach number and aileron angle.



(b) $M=0.882$; $\alpha_L=0.7^\circ$ Up; $C_{H\alpha}=-0.015$.



Figure 11.- Continued.

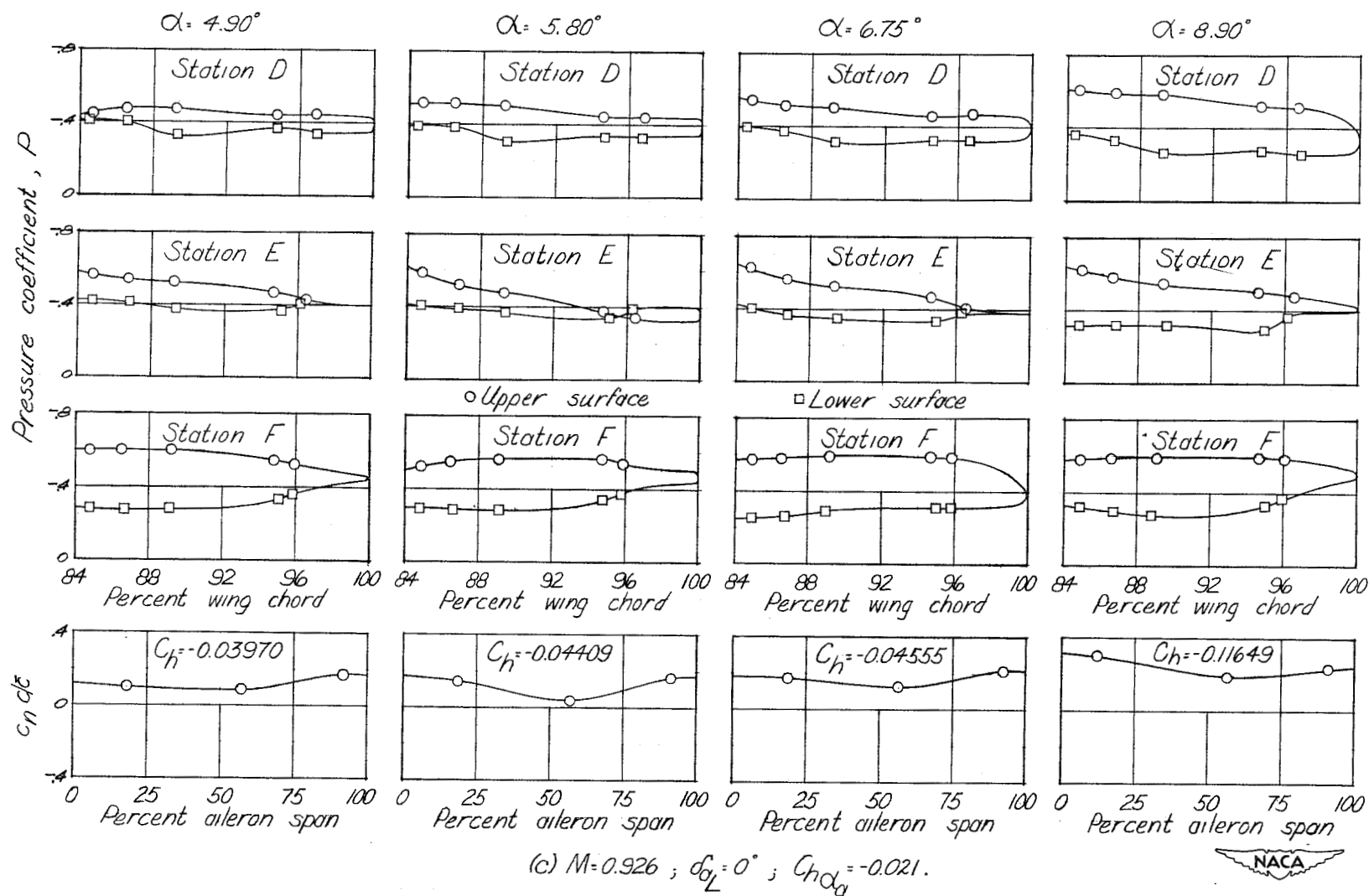


Figure 11.- Continued.

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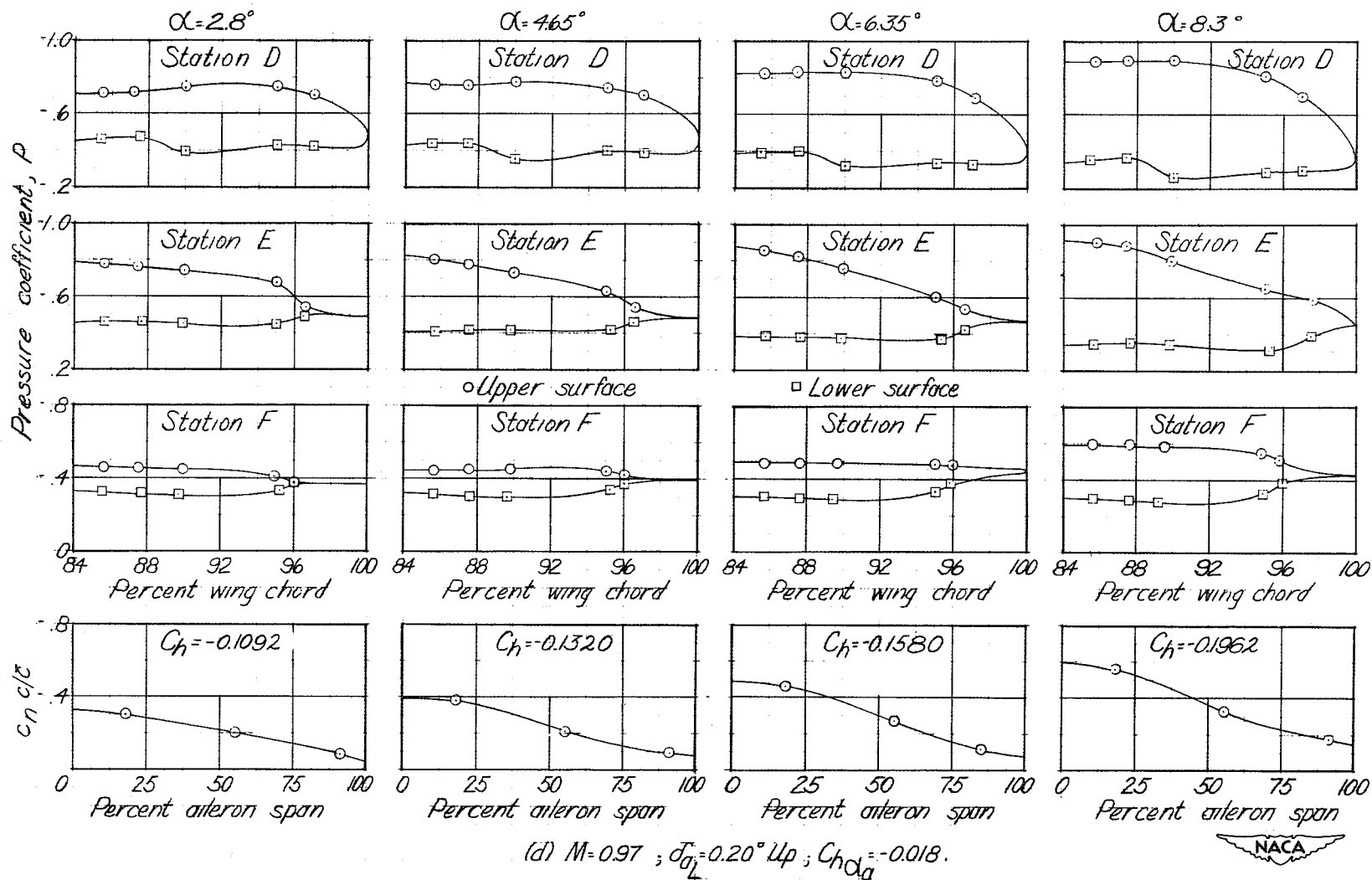


Figure 11.- Concluded.

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